Warehouse Layout Design: Drinking Water Factory

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Abstract

Warehouse layout is an important element that affects the warehouse operating system and occupies the highest cost in logistic activities. Therefore, the warehouse layout should be effectively designed. The objective of this research was to design a warehouse layout for a drinking water factory to optimize its new warehouse space. The ABC classification was used to categorize 10 selected products into class A, B, and C. The concepts of traditional and non-traditional warehouse layouts were used to design three alternative layouts. Linear programming was used to assign the locations of the products in each alternative layout. Finally, the Analytical Hierarchy Process (AHP) was applied to evaluate and select the most proper layout. The results from AHP showed that the layout designed based on the traditional layout concept, horizontal picking rows, was the proper layout. It provided the minimum total traveling distances of about 4,150.7 meters, the setup cost of about 189,900 Thai baht, and the space utilization with the storage area of 221.16 square meters. This research provides two contributions to academic literature. Firstly, it presents the application of the ABC classification and linear programming in the context of the Thai industry. Secondly, it applies the AHP to consider multiple criteria in the selection of the proper warehouse layout.

Keywords
Warehouse layout design, Warehouse management, Analytical Hierarchy Process (AHP), ABC classification

1. Introduction
Manufacturers are currently encountering many challenges, such as price war, emerge of new technology and competitors, and fluctuation of customer demand. To sustain and survive in such a rapidly changing environment, the manufacturers need to increase their competitiveness, for example, by improving their capability or reducing their operating costs related to the manufacturing activities.

Logistics are considered as one manufacturing activity that should be managed effectively to achieve the sustainability of manufacturers' performance (Tippayawong et al. 2013). Warehousing is a major element of logistics management that occupies the highest cost (Baker et al. 2009). It involves location selection, sizing, layout design, administration system design, location control, delivery, and data record (Gu et al. 2010) and warehouse operations relate to four major functions: receiving, storage, picking, and shipping (Gu et al. 2007).

From the review of literature, studies on warehouse management focus mainly on two aspects: internal operating system and warehouse layout design (Van den Berg 1999; Rouwenhorst et al. 2000; Gu et al. 2010). In terms of the internal warehouse operating system, item picking is a key operation in managing a warehouse, which presents 65% of the total operating cost of the warehouse (Thompkin et al 2010; Strack and Pochet 2010). Many studies have developed support systems for item picking by focusing on storage layout to maximize the performance of item picking, such as the utilization of the ABC classification for product classification and reducing average travel time (Zeng et al. 2003) or the application of linear programming to assign the location of the items in the warehouse (Tippayawong et al. 2013; Kasemset and Rinkham 2011). Although the ABC classification and linear programming have been successfully implemented in many industries. However, they are rarely adopted in the Thai industry (Tippayawong et al. 2013).

Focusing on studies on warehouse layout, the design of a warehouse is a complex task because it involves many trade-offs between conflicting objectives and feasibility designs (Dukic and Opetik 2016). Many studies have applied the different concepts to design the warehouse layout, for example, Dukic and Opetuk (2016) applied the concept of traditional and non-traditional layout warehouse concept to design the warehouse layout and discussed the impact of each layout type. Although there are many concepts are used to design layouts, the final selection of those designed layouts is often based on one specific criteria, such as minimum handling cost, travel distances, or the closeness rating Dukic and Opetuk (2016). There are few studies that consider multiple criteria together in the selection of the final warehouse layout.

The case study factory of this research is a drinking water factory located in Chiang Mai Province, northern Thailand. This factory produces and distributes its products – e.g., Polyethylene Terephthalate (PET) bottled drinking water, opaque plastic bottled drinking water and plastic cupped drinking water – to areas in Chiang Mai and close provinces. Due to the increasing number of customer demands, the case study factory aimed to increase its production capacity and thus built a new warehouse to store more products. This research aims to propose a proper warehouse layout for a case study factory by applying several techniques discussed, including warehouse layout design concepts, ABC classification, linear programming, and an Analytic Hierarchy Process (AHP) as the research aims to consider multi-criteria for the final selection of the layout.

The structure of this paper is organized as follows. The second section discusses the related theories in this research used to design the warehouse layout of the case study. This is followed by the third section that presents the method of this research. The fourth section provides a discussion of the results. The last section offers the conclusion of this research.

2. Related Theories

This section discusses the theories used in the design of warehouse layout, including warehouse layout design, ABC classification, and the Analytic Hierarchy Process (AHP).

2.1 Warehouse Layout Design

There are two types of warehouse layouts discussed in a study by Dukic and Opetuk (2016): traditional and non-traditional warehouse layouts. The traditional warehouse layouts are demonstrated in Figure 1. The traditional layout design is based on many assumptions. The two most restrictive are that cross-aisles are straight and must meet picking aisles only at right angles and the picking aisles are straight and are oriented in the same direction (Dukic and Opetuk 2016). These design assumptions limit efficiency and productivity as they require workers to travel longer distances and to take less-direction routes to retrieve products from racks and deliver them to designated pickup-and-deposit points (Meller and Gue 2009).

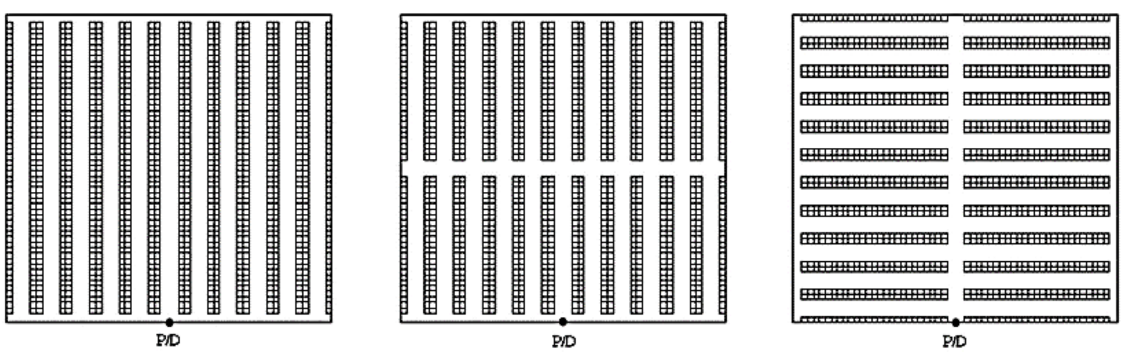

Figure 1 Traditional warehouse layout

In the warehouse layout that maintains parallel picking aisles but allows the cross-aisle to take a different shape, the expected distance to be traveled to retrieve a single pallet is 10% shorter than that in an equivalent traditional design (Dukic and Opetuk 2016). That layout is named the fishbone layout. The fishbone layout incorporates the V-shaped cross-aisles, with the V extending across the entire warehouse. The picking aisles below the V are horizontal, while the aisles above the V are vertical. The expected distance to a pick in the fishbone layout is about 20% shorter than that in a traditional warehouse layout. A drawback of the fishbone design is limited access to the storage space due to the single central pick and delivery point (Dukic and Opetuk 2016).

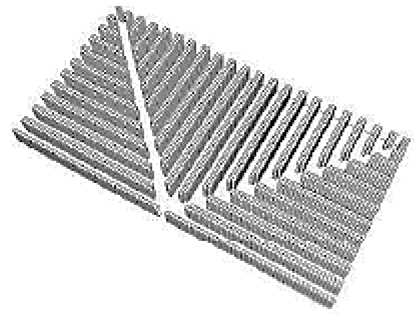

Figure 2 Non-traditional warehouse layout, Fishbone

2.2 ABC Classification

An ABC classification is a class-based clustering technique in inventory management for classifying the inventory based on the items' consumption values (Pholpipattanaphong and Ramingwong 2021). Consumption value is the total value of an item consumed over a specified period, such as a year. The ABC classification is based on the Pareto principle to help manage what matters – the 80/20 rule where 80% of the output is determined by 20% of the input.

- Items in class A are those in which the consumption value is the highest about 80% of a total value. Applying the Pareto principle, they comprise a relatively small number of items but have a relatively high consumption value. Logically, the analysis and control of this class are relatively intense because there is the greatest potential to reduce costs or losses.
- Items in class B are inter-classed items. Their consumption values are lower than items in class A but higher than items in class C.
- Items in class C have the lowest consumption value. This class has a relatively high proportion of the total number of lines but with relatively low consumption values (about 20% to a total value). Logically, it is not usually cost-effective to deploy tight inventory controls, as the value at risk of significant loss is relatively low.

2.3 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making (MCDM) tool to deal with complex, and multi-attribute problems which have been introduced by Saaty (1980). The most creative part of decision making which has an important effect on the outcome is modeling the problem. Identification of the decision hierarchy is the key to success in using the AHP (Kuwaiti et al 2017). The AHP is about the formalization of a complex problem using the hierarchical structure and it is a multi-criteria decision-making approach that employs pairwise comparison. The AHP contains three basic steps: (1) design of the decision hierarchy; (2) the prioritization procedure; and (3) calculation of results.

Initially, the AHP breaks down a complex multi-criteria decision-making problem into a hierarchy of interrelated decision elements. The objectives, criteria, and alternatives are arranged in a hierarchical structure like a family tree. A hierarchy has at least three levels: the overall goal of the problems at the top, multiple criteria that define alternatives in the middle, and competing alternatives at the bottom (Figure 3) (Taherdoost 2017). The process of building this structure not only helps to identify all elements of the decision more precisely but also to recognize the interrelationships between them.

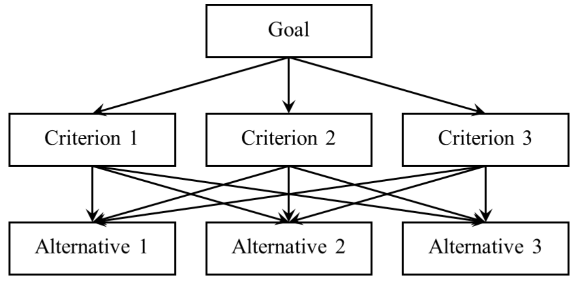

Figure 3. Multi-criteria decision-making hierarchal Structure

When the problems and hierarchy structure has been constructed, the prioritization process begins to determine the relative importance of the elements within each level. The pair-wise judgment starts from the second level (first level of criteria) and ends in the lowest level, alternatives. In each level, the elements are compared pairwise according to their levels of influence and based on the specified element in the higher level. The decision-makers may use concrete data from the alternative or their preference for their judgment between each pair of elements (collecting input data of decision elements) (Albayrak and Erensal 2003).

After forming the preference matrices, the mathematical process commences to normalize and find the priority weight for each matrix (using the eigenvalue method to estimate the relative weight of the decision elements and rating the decision alternatives).

It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments given by the decision-makers. Saaty (1980) suggests a simple procedure for checking on consistency. Then the AHP process determines the consistency ratio (CR) for all matrices. If the CR value is larger than 0.10, which is the acceptance upper limit for CR, it implies that there is a 10% chance that the elements have not been properly compared. In this case, the decision-maker must review the comparison they have made again.

3. Methods

The steps to conduct this research is summarized in Figure 4. Initially, all relevant data for designing the warehouse layout were collected. The data included a list of products expected to be stored in this new warehouse, the size of the warehouse, the previous 3 months' product orders, and the number of pallets for those products. After that, the selected products were classified using ABC classification considering the number of historical orders. The alternative layouts were designed based on the traditional and non-traditional warehouse design concept. A linear programming technique was then developed to assign the location of the products in each alternative layout. Lastly, the alternative warehouse layouts were selected using the AHP technique.

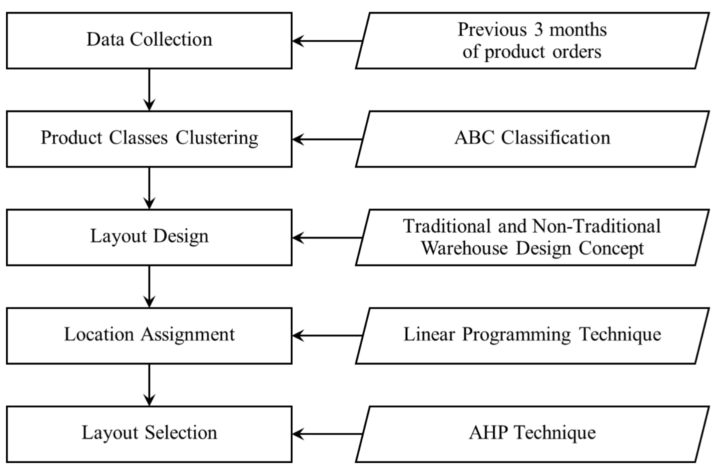

Figure 4. Flow chart of the methodology for warehouse layout design

4. Results and Discussion

4.1 Data Collection

The new warehouse area of the case study factory was 30 m x 18 m or 540 m^2. The supporting office was located at the bottom right of the layout and the warehouse door (I/O) was next to the office, as shown in Figure 5. There were 10 product items expected to be stored in this warehouse (shown in Table 1), including large PE bottles, glass bottles, 600 cc PET bottles, 18.9 cc PC bottles, 1,000 cc plastic bottles, 350 cc PET bottles, plastic cups, 1,500 cc PET bottles, and 250 cc M bottles. Historical data of each product in terms of the number of orders in selected 3 months were collected.

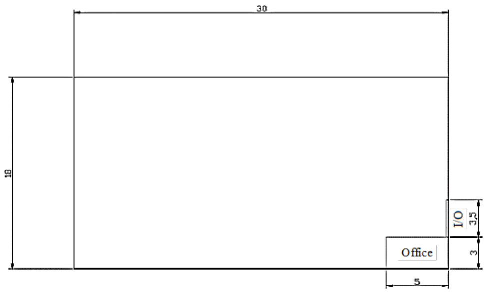

Figure 5. New warehouse area of the case study factory

4.2 Product Classes Clustering

The average number of orders was used to categorize the 10 selected products into class A, B, and C. As shown in Table 1, Class A, consisting of 2 product items: large PE and glass bottles, represented the highest number of orders that contributed to approximately 64% of the total quantity of orders. Class B, consisting of 3 product items: 600 cc PET, 18.9 cc PC, and 950 cc M bottlers, contributed to about 24% of the total quantity of orders. While the remaining 5 product items were grouped into class C.

The historical number of pallets for storing these products was also collected. Based on the previous data, the average number of pallets needed for the 10 product items in the new warehouse was 191 pallets in total, including class A 150 pallets, class B, 19 pallets, and class C 22 pallets. These pallets needed a total area of 275 m^2.

Table 1. List of product items and ABC Classification

Product items	The average number of orders in 3 months (units)	Percent of orders	Cumulative percent of orders	Percent of product items	Class	Pallets needed
Large PE Bottles	326,474	52.61	52.61	20	A	150
Glass Bottles	19,750	11.50	64.11		A	
600 cc PET bottles	15,925	9.27	73.38	30	B	19
18.9 cc PC Bottles	12,861	7.49	80.87		B	
950 cc M bottles	12,449	7.25	88.11		B	
1000 cc plastic bottles	76,981	4.65	92.76	50	C	22
350 cc PET bottles	7,555	4.40	97.16		C	
Plastic cups	2,543	1.48	98.64		C	
1500 cc PET bottles	1,805	1.05	99.69		C	
250 cc M bottles	533	0.30	100.00		C	

4.3 Layout Design

Based on traditional and non-traditional warehouse layout design concepts, three alternative layouts were designed. According to the safety standards, we used 1.2 m. for the walkway width.

Layout A (Figure 6) was designed according to the traditional warehouse layout concept, horizontal picking rows. As seen, all pallets are arranged parallel to the long side of the warehouse. This layout can store 211 pallets with an area used of approximately 303.84 m^2.

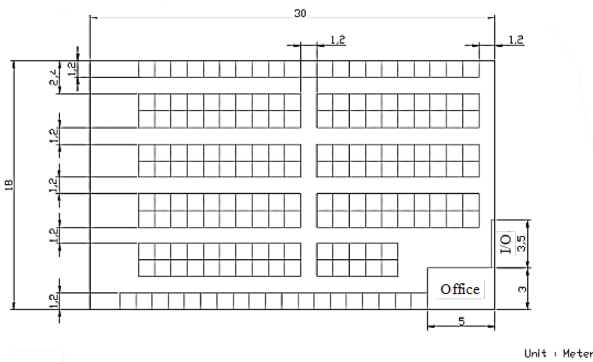

Figure 6. Layout A, traditional warehouse layout with horizontal picking rows

Layout B (Figure 7) was also designed based on the concept of traditional warehouse layout, vertical picking rows. All pallets are arranged parallel to the width side of the warehouse. This layout can store 206 pallets with an area used of approximately 296.64 m^2.

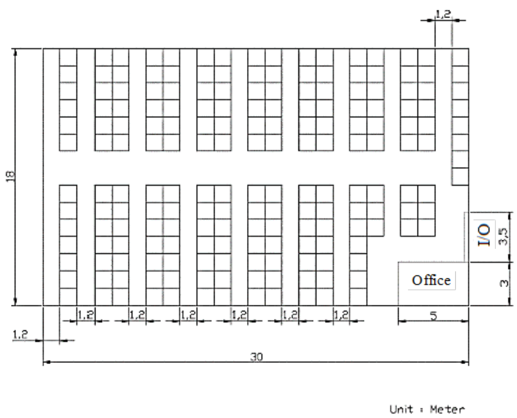

Figure 7. Layout B, traditional warehouse layout with vertical picking rows

Layout C (Figure 8) was designed differently based on the non-traditional warehouse layout, namely the fishbone layout. This layout combines the vertical picking rows of a traditional warehouse with a second set of horizontal picking rows, divided by a V-shaped diagonal alley crossing the entire warehouse. The layout can store 217 pallets with an area used of 312.48 m^2.

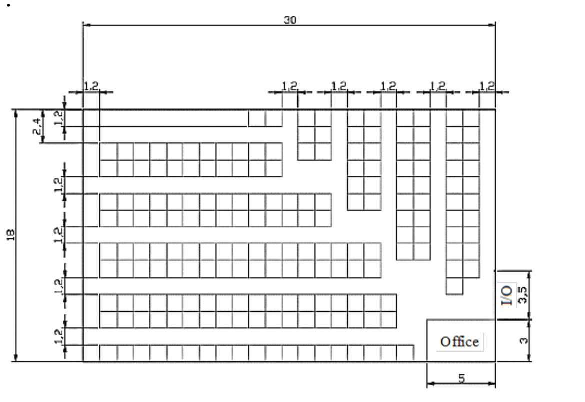

Figure 8. Layout C non-traditional warehouse layout, fishbone layout

4.4 Location Assignment

The mathematical model was developed to assign the location of product items. Based on linear programming, the mathematical model of the problem can be formulated as follows:

Minimize $$Min \sum_{i=1}^{m} \sum_{i=1}^{n} D_{ij} x_{ij} \quad (1)$$

Subject to $$\sum_{j=1}^{N} x_{ij} = S_i \qquad \forall_i = 1,2, \dots, M \quad (2)$$

$$\sum_{i=1}^{M} x_{ij} \leq N \qquad j = 1,2,3 \dots, N \quad (3)$$

Where
- D_{ij} is the transfer distance of commodity i to destination j
- S_i is the maximum capacity of destination j
- x_{ij} is the available product i in destination j
- i is the number of commodities (i = 1,2,3, …, M)
- j is the number of destinations (j = 1,2,3,…, N)

The mathematical model, equation (1), aimed to minimize the traveling distance of products from the origins (door) to destinations (location). Constraint (2) represented the total amount of a commodity i at destination j should be equal to the demand of the commodity. Constraint (3) stated that the total amount of a commodity i should not exceed the maximum capacity of destination j. Constraint (4) addressed that if the product i was assigned to destination j, the value of this variable was either 1 or 0. The formulated mathematical model was employed to evaluate the warehouse arrangement efficiency by considering the total traveling time of all product items.
The mathematical model was run by using an Excel solver to assign the location of each product class in each alternative layout. The results from the excel solver run showed in Figures 9, 10, and 11.

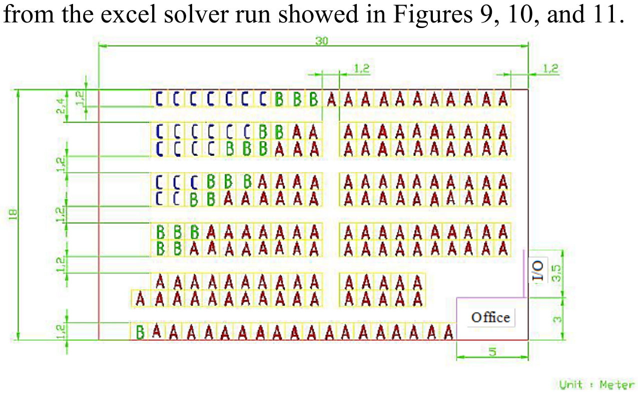

Figure 9. Location of product class assigned in Layout A

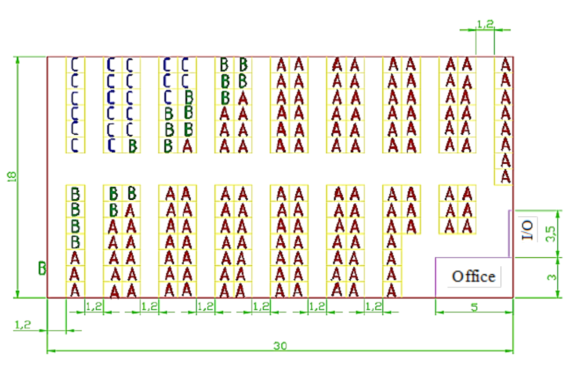

Figure 10. Location of product class assigned in Layout B

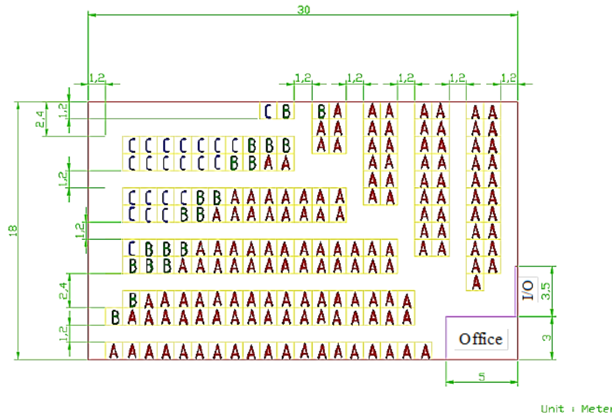

Figure 11. Location of product class assigned in Layout C

A summary of the travel distances, total setup cost, and utilization of area in each alternative layout was presented in Tables 2, 3, and 4, respectively.

Table 2. Total travel distance

Alternative layout	Total Traveling distance (m)			Total distance (m)
	Class A products	Class B products	Class C products	
Layout A	2,797.5	576.2	777	4,150.7
Layout B	3,513.6	687	925.2	5,125.8
Layout C	3,555.2	667	832.6	5,054.8

Table 3. Total setup cost

Alternative layout	Maximum quantity of pallets	Pallet price (Thai Baht)	Total cost (Thai Baht)
Layout A	211	900	189,900
Layout B	206	900	185,400
Layout C	217	900	195,300

Table 4. Utilization of warehouse area

Alternative layout	Maximum quantity of pallets	Areas for pallets (m^2)	Areas for walkway (m^2)
Layout A	211	303.84	221.16
Layout B	206	296.64	228.36
Layout C	217	312.48	212.52

4.5 Layout Selection

In using the AHP, we developed a hierarchical structure of a model for selecting the suitable warehouse layout for the case study (Figure 9). The goal which was the proper warehouse layout was positioned at the top. Three criteria for considering alternative layouts were placed in the middle, including traval distance, setup cost, and utilization of warehouse area. Three alternative layouts A, B, and C were set in the bottom.

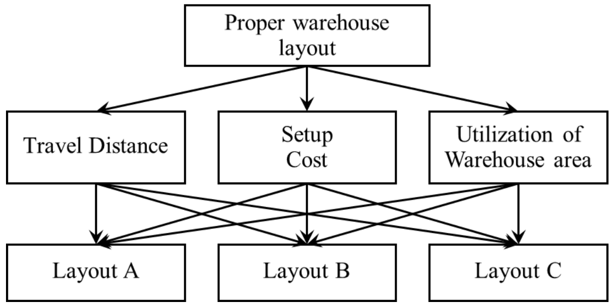

Figure 9. A hierarchal Structure for layout selection

From the pairwise judgment by the 6 warehouse staff who was working in the case study factory, the results are presented in Table 5. As shown, the travel distance was scored the highest weight at 78%, while the setup cost and area utilization criteria were scored lower at 15.5% and 6.8%, respectively. The CR ratio was 0.69 which was less than 0.1; therefore, these judgments were accepted and properly compared. After pairwise comparison of the criteria, the pairwise comparisons among designed warehouse layouts were conducted to identify the score of each designs. Thee total score results are shown in Table 6. Table 7 shows the results of the calculation of the Weight average.

Table 5: Pairwise comparison for selected criteria

Criteria	Travel distance	Setup Cost	Area Utilization	Criteria Weight	Consistency (CI/RI)
1. Travel distance	1	7	9	0.780	0.069
2. Setup cost	1/7	1	3	0.155	
3. Area utilization	1/9	1/3	1	0.068	

Table 6: Total score from all judges

Alternative layout	Layout A	Layout B	Layout C
1. Travel distance	0.741	0.195	0.064
2. Setup cost	0.063	0.337	0.600
3. Area utilization	0.067	0.244	0.689

Table 7: Weight average

Alternative layout	Calculation	Weight average
Layout A	(0.780)(0.741) + (0.155)(0.063) + (0.068)(0.067)	0.59230
Layout B	(0.780)(0.195) + (0.155)(0.337) + (0.068)(0.244)	0.22093
Layout C	(0.780)(0.064) + (0.155)(0.600) + (0.068)(0.689)	0.18980

As shown in Table 7, the results from the AHP suggested selecting layout A because the weight average was the highest at 0.59230. Layout A was designed based on the traditional layout design with horizontal picking rows (Dukic and Opetuk 2016). This layout provided the lowest total travel distance of 4,150 meters, the setup cost of 189,900 Thai baht, and the space utilization with the storage areas of 221.16 square meters.

5. Conclusion

The objective of this research was to design a warehouse layout for a drinking water factory to optimize its new warehouse space. The research applied the ABC classification to categorize 10 selected products into class A, B, and C, based on the historical data of product orders. The concepts of traditional and non-traditional warehouse layouts were used to design three alternative layouts, including (1) the traditional layout concept, horizontal picking rows; (2) (1) the traditional layout concept, vertical picking rows; and (3) fishbone layout. The linear programming was used to assign the locations of the products in each alternative layout to minimize the travel distance. Finally, the Analytical Hierarchy Process (AHP) was applied to evaluate and select the most appropriate layout, considering three criteria, which included travel distance, setup cost, and area utilization. The results from AHP showed that the proper layout should be the one designed based on the traditional layout concept, horizontal picking rows because this layout provided the lowest total travel distances of about 4,150.7 meters, the setup cost of about 189,900 Thai baht, and the space utilization with the storage areas of 221.16 square meters.

This research provides two contributions to academic literature. Firstly, there are limited studies that applied the ABC classification and linear programming in the design of layout in Thai industries (Tippayawong et al. 2013); therefore, this research can fulfill this gap by presenting the application of these techniques in the Thai water drinking factory. Secondly, most studies on layout designs select the final layout based on one specific criterion; however, few studies consider multiple criteria in such selection. This research thus applies the AHP to consider multiple criteria in the selection of the proper warehouse layout.

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